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TEACHING TIMBER ENGINEERING

Richard Harris[1], Wen-Shao Chang[2]

ABSTRACT: For the future success of timber structures, timber engineering teaching needs to be embedded in the mainstream curriculum for undergraduate students. Course content should be selected for students to gain an essential understanding, with the opportunity for progress to more advanced high level (Masters) courses if the need and opportunity arise. This paper discusses the key issues and proposes teaching content and technique to create a basic understanding of the subject in order to give students sufficient respect for the material, without discouraging them from its use. It outlines the need for Industry input in University teaching and research and discusses the form this should take.

KEYWORDS: Timber Engineering, Teaching

1 INTRODUCTION

Some in the timber engineering industry question why university graduates have limited knowledge in timber engineering. In the UK, university courses provide a relatively short period of full-time education (3 or 4 years) to create an academic base. Professional qualification, through the Institution of Civil Engineers and/or the Institution of Structural Engineers, usually follows after some 4 years of post-graduate, supervised training.

Ways and means of promoting timber through teaching have been discussed for many years.

This paper seeks to set out methods observed and used by the authors and to examine the levels of learning appropriate to each stage of a structural engineer's career and promote discussion of how the timber industry should seek to support teaching and promote best practice.

2 BASIC KNOWLEDGE OR INNOVATIVE ENGINEERING

Many think that structural engineering design is about sizing members but this is not design, it is sizing. Design is more complex. It is about choosing an appropriate structural system, coordinating it with the architecture and environmental design, choosing appropriate materials and finding appropriate foundation and construction methods. As little as15% of a structural engineer's job is about analysis and setting down a satisfactory justification, in numbers, as proof of the design.

In the UK, as in many countries, structural engineering is taught as part of a civil engineering or general engineering curriculum and taught aspects account for a small proportion of the whole course. Timber engineering is learnt as part of structural engineering, which is the discipline that covers areas such as structural analysis and design, structural mechanics, foundation design and properties of materials. It is clear that structural engineering is a complex integrated process and the graduate engineer is unlikely to have gained much specific experience of timber design in their course. But neither are they likely to have achieved much experience in the detail design of steel or concrete. For a graduate to leave university with a basic grasp of the key elements of timber engineering, it is important to use the small time available in the curriculum effectively.

Timber is a complex material. Its anisotropy and inhomogeneity set it apart from the other main structural materials. One could say that steel is simple – not only is it isotropic and homogenous, it is forgiving in the way that it yields to give advanced indication of overload and provide opportunity for redistribution. Whilst reinforced concrete is anisotropic, its strength comes from its embedded steel, with the all the advantages of that material.

To use timber well, an engineer must have a thorough understanding of its basic properties. If an engineer fails to learn this basic knowledge at university, are they condemned to a lifetime of designing in steel and

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concrete? Clearly not, but where do they learn the skills to make the most of this low embodied carbon, renewable material? How does an engineer move safely from using timber for low-tech traditional structures, such as load-bearing stud wall (Figure 1), and move into the design of more advanced longspan and tall structures, using the myriad of innovative materials and methods.

Figure 1: *Load-bearing timber stud wall structure*

Is there such a thing as a simple timber building? Even the most basic structure uses modern products (Figure 2). Timber I-Joists have been in use for many years but they demand good engineering understanding for their success and they should only be designed and specified by engineers with a proper understanding of the use of wood.

Figure 2: *Timber I-Joists in stud wall structure*

On the other hand, with a good understanding of the basics of timber engineering, why should a long glulam beam require high levels of timber? (Figure 3)

Figure 3: *Eton Manor – London 2013 Venue. 330 x 2450 GL24h glulam beams – 49 metre span (Photo: Peter Steer)*

Experienced engineers, expert in the design of timber structures, designed all the projects in the figures. What errors might an inadequately trained engineer make?

3 THE UNDERGRADATE COURSE

The academic base for professional design engineers, in the UK, is provided by a “Civil Engineering” degree, which contains a range of subjects including mathematics, the theory of mechanics, materials science, structural engineering and practice (e.g. the background to and use of codes), engineering practice (e.g. management studies), project work and specialist options.

Timber engineering is learnt as part of structural engineering, which itself only accounts for around 15% of the course. Clearly the graduate engineer is unlikely to have gained much specific experience of timber design in their course. But neither are they likely to have achieved much experience in the detail design of steel or concrete. In this context it is important to choose course content carefully.

3.1 PLANTING THE SEED OF TIMBER ENGINEERING

The objective at undergraduate level is to develop analytical and conceptual understanding of structural action, through the design of elements and simple structures, and to introduce elements of construction technology as applied to timber construction (Figure 4). Structural engineering is much more than sizing members; it is more complex and course content should reflect the need for an overall understanding of the behaviour of timber, embedding sufficient knowledge and skill to enable a graduate to respect the material and yet use it with confidence – knowing when they need to call for specialist advice.

Figure 4: *Teaching Undergraduates – give the knowledge to respect timber and the understanding to be confident in using it (Photo: The University of Bath)*

3.2 COURSE CONTENT

There are three key elements of learning for an undergraduate studying Structural Engineering

- Fundamentals of structural mechanics
- Basic materials science
- Understanding of how structures go together

Clearly some elements lie outside the Timber Engineering course, which needs to funnel the basic understanding into the specifics of the material. The key knowledge for structural engineers lies in mechanics and the mathematics that underpins it. This lies outside the scope of this paper but of course timber engineering learning should provide feedback to build on what is learnt elsewhere in the course. Integration between units on a course is essential.

Failure of structures often relates to issues not dealt with in codes. The report [1] gives the following as the commonest causes of failure of timber structures:

Bracing to avoid instability problems both in the finished structure and during construction; Situations with risk for perpendicular to grain failure (orthotropy); Consideration of moisture effects (shrinking and swelling); Design of joints. Fire safety and communication in design and building team are also important.

Professor Buchanan at the University of Canterbury in New Zealand has built a very strong undergraduate course that includes elements of classroom learning, self-learning through simple testing and project work, particularly in the form of a competitive design and make bridge project. During the author's visit in 2010, Prof Buchanan demonstrated the use of very simple tests that students could use to discover basic material properties (Figure 5). A number of groups perform the same tests, enabling the results to be combined, demonstrating variation and statistical techniques for determining safe material parameters.

Figure 5: *Professor Andy Buchanan demonstrates the use of a simple test rig at the University of Canterbury, used by students to obtain bending characteristics of timber*

In the UK, Industry has come to expect that the basics of the use of codes and design method are learnt at university and so there is a strong logic in placing teaching into the context of the design rules.

Learning about how buildings go together comes from studying precedents, both in abstract through site visits and in the application, through project work.

Table 1 shows how timber engineering course content might give intuitive understanding of behaviour, with the structure of wood as a first step and fire and durability being included at the end, to reinforce their importance. Sizing techniques need to be included to demonstrate how codes incorporate methods to respond to moisture and load duration.

Table 1: *Course Content*

Topic	Content
1. Origins	Wood Structure; Species; Supply
2. Code Basis	Action combination; Design values
3. Properties	Grading; Strength classes; Moisture content; Load duration; Specification
4. Member sizing	Flexural, Compression, Tension members
5. Connections	Connections; European Yield Model; Nails; Screws; Bolts
6. Wood products	Glulam; LVL, CLT, Plywood, + products
7. Long life	Fire, Durability

3.3 PROJECTS

Structural design is a complex, non-linear process. To enable students to understand they need to work on projects throughout their course. They need to see and experience precedents and, from the very start, learn approximate solution methods. This gives them a chance to pick up complex design skills and, as the course develops, makes sense of the structural and material behaviour.

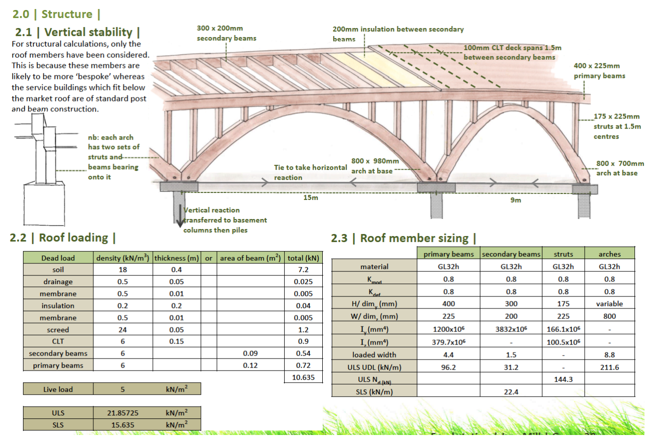
When students graduate they will work in multi-discipline design teams and so gain experience in the less pressured context of University (although, with marks paramount in the minds of students, they may dispute that University is less pressured than real life!)

In the design projects at the University of Bath, students are encouraged to be creative and aspire to stretch the limits of their ability and the scope of the material they choose to work with. Within that context there is a balance to be found. Being a joint department of Architecture and Civil Engineering, the architects help to raise the design aspirations of the engineers, whilst the engineers bring context and feasibility to the architects.

Figure 6: *Final year student design project – Architects Impression of design for a market space – long span structures with a heavily loaded (planted) roof. (Image: Harry Strueli, Annette Davis, Steven Bekkers (architectural students) Jess Mill (Civil and Architectural Engineering student), Jenny Pollard (Civil Engineering student))*

Figure 6 shows an image from the design report from a final year architecture-engineering joint project report. It is from one of thirty two teams, more than half of whom selected timber structures. In the real world less than ten percent of structures of this type are actually constructed in timber but enabling students to work to a feasible solution encourages them to continue to use the skills they have developed, after they have graduated.

The page from the structural engineering student's report (Figure 7) shows the extent of knowledge and skill developed in the undergraduate course. The architects have learnt that timber structures are visually larger than steel and that timber should be protected from water. As well as using their structural mechanics, the engineers have understood that timber has limitations in cross grain capacity, that it works well in compression and that products and techniques can be designed to carry heavy loads over long spans.



2.0 | Structure |

2.1 | Vertical stability |

For structural calculations, only the roof members have been considered. This is because these members are likely to be more 'bespoke' whereas the service buildings which fit below the market roof are of standard post and beam construction.

2.2 | Roof loading |

Dead load	density (kN/m^3)	thickness (m)	or	area of beam (m^2)	total (kN)
soil	18	0.4			7.2
drainage	0.5	0.05			0.025
membrane	0.5	0.01			0.005
insulation	0.2	0.2			0.04
membrane	0.5	0.01			0.005
screed	24	0.05			1.2
CLT	6	0.15			0.9
secondary beams	6			0.09	0.54
primary beams	6			0.12	0.72
					10.635

Live load	5	kN/m^2
ULS	21.85725	kN/m^2
SLS	15.635	kN/m^2

2.3 | Roof member sizing |

	primary beams	secondary beams	struts	arches
material	GL32h	GL32h	GL32h	GL32h
K_{mod}	0.8	0.8	0.8	0.8
K_{def}	0.8	0.8	0.8	0.8
H/ dim_y (mm)	400	300	175	variable
W/ dim_z (mm)	225	200	225	800
I_y (mm^4)	1200x10^6	3832x10^6	166.1x10^6	-
I_z (mm^4)	379.7x10^6	-	100.5x10^6	-
loaded width	4.4	1.5	-	8.8
ULS UDL (kN/m)	96.2	31.2	-	211.6
ULS $N_{d\,(kN)}$			144.3	
SLS (kN/m)		22.4		

Figure 7: *Final year design project – Engineer's summary of deisgn parameters and structural components (Image: Jess Mill (Civil and Architectural Engineering student)*

Ideally, the course should include a design and make element but class size can preclude this at undergraduate level. There are two institutions in the world that specialise in design and make courses. Prof Pekka Heikkinen at Aalto University in Finland offers a one year intensive programme focusing on wood and wooden architecture.

His Wood Program is a unique and challenging one year, tuition-fee-based programme, designed to attract architects and students of architecture, with a Bachelor's degree or at least three years of studies in architecture, landscape architecture or related fields. It deals with topics such as ecology of forests and wood, technical properties of wood, wood as a building material, the tradition of wooden buildings, maintenance and renovation of wooden buildings and modern wood architecture.

Professor Andrew Freear is director of The Rural Studio, in Alabama USA. Here final year architecture students from Auburn University take two academic years to design and build a project for their community in Hale County.

The results of both these Design and Make courses are remarkable (Figure 8). But such projects are focused on architects and are well beyond the scope of introduction into engineering courses.

As mentioned above, Professor Buchanan uses a design competition for a bridge across a stream at the university campus – the winner being the bridge that stands with the load of two people but collapses with three – a clever way of ensuring that the structure does not use too much material. The project is well sponsored by local industry and the students win a worthwhile monetary prize as well as kudos.

Figure 8: Example of Rural Studio Project (2010). Akron Boys and Girls Club, designed and built by Whitney Hall, John Marusich, Adam Pearce, Danny Wicke (Final year architecture students). The project includes a space covered by a timber lamella structure

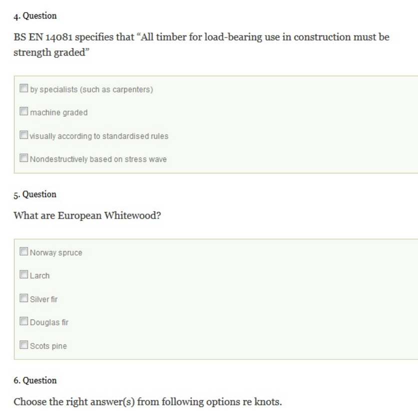
The problem for incorporating design and make into a normal undergraduate course is the time and resources required to make it a unit available for all students within their programme. The scale of project achieved by the Wood Programme and Rural Studio is not possible within the constraints of an undergraduate course. Months are necessary to achieve the construction of a full-size building structure but only days are available.

The University of Bath is trialling a Design and Make Project for joint teams of architecture and engineering students. This is conducted outside the course, over a long weekend, after the end of the formal teaching year. For two days, volunteer teams of students work with tutors from within the department and outside to design a structure. The designs are judged on the third day. By conducting the course within a woodland, at this stage trees can be felled to provide material to make a prototype structure. Following this, all the participating students and tutors work together to build the selected structure. This course will run for the first time in June 2014 and so the results are yet to be evaluated.

3.4 TEACHING AIDS: E-LEARNING

E-Learning offers new opportunities, through interactive examples, for students to reinforce what they learn in lectures and projects. Evernden et al [2] summarised some of the computer aided exercises used in teaching structural understanding. Ibell [3] makes the point that “students are highly computer literate and comfortable with accessing material online” However we must use this material to help support learning, not as a teaching medium in itself.”

Particularly because of the current-day students background in using electronic media, in practice the interaction between physical testing and electronic resources is essential. E-media can be used to embed learning into the course. In the future it is possible that all teaching will be delivered electronically but at present lectures are still live and electronic media is used to enable students to make repeated attempts at tutorials. A very simple question and answer system appears to work well (Figure 9)


4. Question

BS EN 14081 specifies that “All timber for load-bearing use in construction must be strength graded”

- by specialists (such as carpenters)
- machine graded
- visually according to standardised rules
- Nondestructively based on stress wave

5. Question

What are European Whitewood?

- Norway spruce
- Larch
- Silver fir
- Douglas fir
- Scots pine

6. Question

Choose the right answer(s) from following options re knots.

Figure 9: Example of tutorial question and answer as electronic media teaching resource – although simple , it is effective

It is important to give students hands-on experience with the material and so the course includes an element of work in which students make specimens and witness their testing (Figure 10)

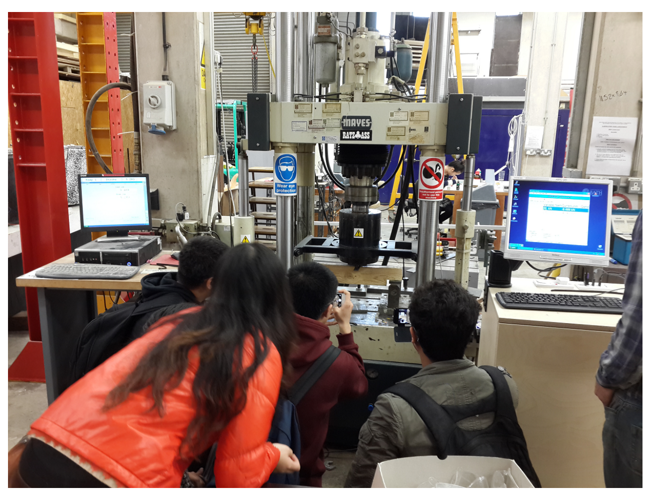


Figure 10: Example of students witnessing test of specimen. In this case, the specimen is a notched beam and the simple objective is to embed understanding of cross-grain weakness

3.5 INDUSTRY CONTRIBUTION

At undergraduate level, industry can enable practitioners to contribute by teaching about real projects and real methods. Industry can give students the opportunity to visit sites and factories as well as give direct work experience in placements, for a summer or for a whole year. As engineers develop their career, Industry should enable them to build specialist skills, by supporting Masters courses and other forms of post-graduate learning. Knowledge Transfer Partnerships can embed and develop specialist knowledge and skill in businesses. In addition, by supporting PhD research, Industry supports development of timber engineering expertise in Universities.

3.6 SITE VISITS

Timber Engineering teaching is not always near to readily available project examples. Industry input in preparing case studies is very important. There are many excellent examples of Case Studies. Both timber trade associations and industrial companies around the world give access to examples of the best engineering in their regions (Table 2).

Table 2: *Examples of Case studies*

Country	Website
Australia	http://www.woodsolutions.com.au
Canada	http://wood-works.ca/
	http://cwc.ca/publications/wood-designbuilding-magazine
Finland	http://www.puuinfo.fi/
New Zealand	http://www.nzwood.co.nz/case-studies/
	http://www.mcintosh.co.nz
UK	www.trada.co.uk/casestudies http://www.woodforgood.com/case-studies/ http://www.xlam-alliance.com/case-studies/ http://rotafix.co.uk/casestudies/

Site visits do more than provide opportunities to demonstrate structural behaviour, construction method and details. A few hours spent looking at timber building structures can provide enthusiasm and motivation for a student to use timber after graduating (Figure 11)

Figure 11: *Site visit with students to a completed roundwood building project at Hooke Park in Dorset*

4 TRAINING POST GRADUATION

Specialist timber engineers often wish to recruit engineers experienced in timber design but they will not find expertise in a typical graduate. For the reasons given above, a graduate from a general Civil Engineering course is unlikely to have had more than a few days of actual design in timber at University.

However, for the student entering a design office, it is likely that they will more readily find support in design of a prospective concrete or steel structure than one in timber. For long-span or tall structures, there is more established expertise in the “conventional” materials than in timber. Even if a graduate arrives enthused with timber as a potential material, they may be demotivated by the reception they receive from the more experienced engineers, whose main materials are steel and concrete. Companies selling timber-engineering products overcome this by having high levels of in-house engineering support. It is clear that the success of innovative timber engineering design in the UK has been achieved through companies building expert teams of designers to support their work. In building these teams, companies have recruited already established and experienced timber engineers but they have added to these with both non-specialist and specialist Masters and PhD graduates.

The establishment of advanced courses of study provides a small number of trained engineers but they are the essential nucleus to build on innovation and take the timber engineering industry forward.

4.1 ADVANCED COURSES

To provide higher levels of expertise, specialist Masters Courses are essential in ensuring that specialist knowledge is embedded in industry. In the UK industry has funded free places available on the MSc Timber Engineering course at Edinburgh Napier University. The content of a Masters course should build on the topics in the topics discussed above for undergraduates. The Napier course is typical in providing Project Management, Analysis & Timber Design, Sustainable Building Design, Timber Materials Application, Timber Form & Construction. Thus it is very similar but has more time to go into the material in depth. The key component of an MSc course is the Dissertation, which enables the student to build on their knowledge using a project.

The primary form of advanced learning in timber engineering at the University of Bath has been through doctorate studies leading to PhD. It has been possible to recruit excellent students, who may not have a background in timber engineering, to research topics relating to timber. To gain grounding in timber engineering, these students register onto the undergraduate course but subsequently, in studying their topic in the depth demanded of a PhD, they graduate with excellent timber engineering skills, suitable for a career in industry.

The COST (European Cooperation in Science and Technology) funding is one of the longest-running European research frameworks supporting cooperation among scientists and researchers across Europe. This has included as one of its nine domains of activity “Forests, their Products and Services. The programme has offered opportunities for networking through conferences and “Short Term Scientific Missions” and training schools (Figure 12 A and B). It has been very influential in building timber engineering knowledge across Europe.

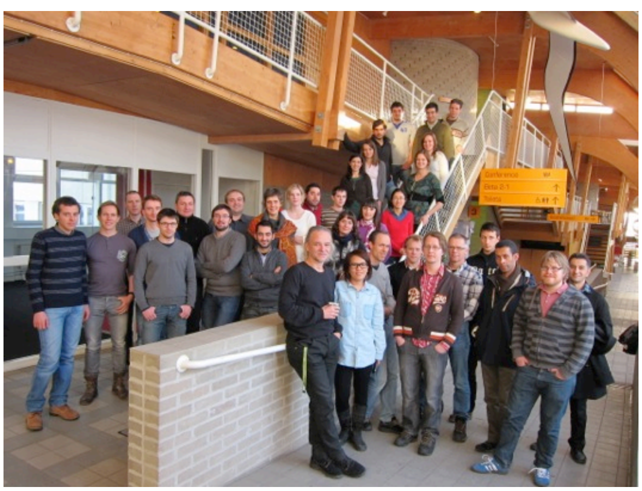


Figure 12A: *COST Action FP1004 Training School ant Lund University School of Civil Engineering. Topic:*

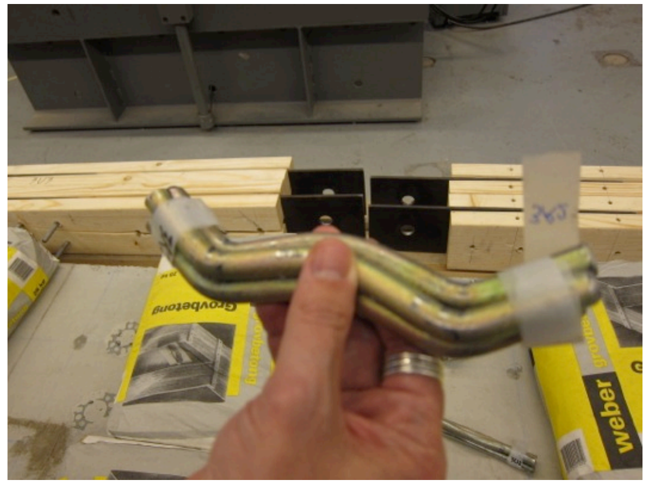


Figure 12B: *COST Action FP1004 Training School – laboratory tests included in programme*

5 CONCLUSIONS

Structural Engineering is about creating real buildings and successful engineers – those who enjoy their work and design buildings to be proud of – are strongly connected to the reality of the construction process. If the timber industry is to embed a basic understanding of use of timber in students, what is needed is its investment, of money (in supporting students), time (in teaching and tutoring) and access to projects, to demonstrate the practical potential for timber use.

All these forms of support have proved effective at the University of Bath, where teaching an introduction to timber engineering to undergraduates, provides support to students in their project work. A strong research group, specializing in timber engineering, provides opportunity for more advanced teaching and graduating masters and PhD students can take specialist knowledge into Industry,

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